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ABSTRACT

Sixty-four fifth and sixth-grade pupils were taught number series extrapolation by either an algorithm, fully prescribed problem-solving method or a heuristic, less prescribed method. The trained problems were within categories of two degrees of complexity. There were 16 subjects in each cell of the 2 by 2 design used. Aptitude Treatment Interaction (ATI) was an object of the research, with short- and long-term instructional effects investigated. Training was given by computer-assisted instruction. Results revealed an over-all superiority of the algorithm programs for both training levels. An ATI was shown between Numerical Ability and the treatment factor only for the less complex problem category. A reverse relation holds for Negative Fear of Failure and treatment, significant in only the more complex problem category. Results of testing done some days after the training session showed opposite overall effects. No ATI's were found here. Further, Field Dependency appeared to be a good predictor of the susceptibility for set fixedness to the trained problem-solving method. (MP)

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TEACHING PROBLEM SOLVING; THE EFFECT OF ALGORITHMIC AND HEURISTIC PROBLEM SOLVING TRAINING IN RELATION TO TASK COMPLEXITY AND RELEVANT APTITUDES

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TEACHING PROBLEM SOLVING; THE EFFECT OF ALGORITHMIC AND HEURISTIC PROBLEM SOLVING TRAINING IN RELATION TO TASK COMPLEXITY AND RELEVANT APTITUDES.

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A total of 64 fifth and sixth grade elementary school pupils were taught number series extrapolation by one of two kinds of problem solving methods: an algorithmic (fully prescribed) or a heuristic (less prescribed) one. The trained problems were within categories of two degrees of complexity, determined by the number of problem-subtypes within each. There were 16 subjects in each cell of the 2 x 2 design. Aptitude-treatment interaction (ATI) was object of research too. Training was given by computer-assisted instruction (CAI). Horizontal, vertical and non-specific transfer-testscores were criteria too. Short- and long-term effects were investigated.
Results from the Instruction Problems Test taken at the end of the last training session revealed for both levels of task complexity an over-all superiority of the algorithmic programs. Besides this an ATI was shown between the aptitude Numerical Ability and the algorithmic/heuristic treatment factor. This ATI is significant for the less complex problem category only. The reverse relation holds for the interaction between Negative Fear of Failure and the mentioned treatment factor: this is significant only for the more complex problem category. The results of the Instruction Problems Test taken some days after the training session show opposite over-all effects. This is caused by a rather sharp drop within the algorithmic level; no ATI's were found here.
For the vertical transfertest ATI of Negative Fear of Failure and the algorithmic/heuristic factor was found. For the horizontal and non-specific transfer neither main effects nor interactions were found. Field-dependency appeared to be a good predictor of the susceptibility for set, fixedness to the trained problem solving method.

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Teaching Problem Solving; The Effect of Algorithmic and Heuristic Problem Solving Training in Relation to Task Complexity and Relevant Aptitudes

The teaching of problem solving has been attempted for a long time. Selz (1935) reports remarkable success from systematic training programs given to elementary school pupils.

Teaching thinking or problem solving can be done by training pupils in using adequate problem solving methods. What kind of problem solving methods are adequate? Some primary questions are connected with this point: First, what are the important dimensions of problem solving methods? Second , what are the important criteria for the effectiveness of problem solving training? Third, are there so-called aptitude treatment interactions between important treatment dimensions and certain personality variables? Finally, are the differential effects of the treatments the same for all criteria or not?

One important dimension of problem solving methods is the degree of prescribedness of the solution process. One can prescribe the solution process in detail, leaving nothing to the invention of the pupil. This kind of sulution process is described by the Russion psychologist Landa (1969) as an algorithmic one: a series of operations and decisions, which, if run through in the proper way, offers solution guarantee. This is what is called, a TOTE-system by Miller, Galanter and Pribram (1960). Landa has taught algorithmic processes to pupils to help them master complex grammatical rules from the Russian language.

One could leave more thinking steps to the pupil's invention, however, by letting him discover certain relations by himself. In this situation, help

can be given it it is asked for or if the pupil makes too many mistakes. In this case, one is teaching problem solving in a heuristic way. In this situation there is no solution guarantee. Algorithmic and heuristic problem solving methods do not form a dichotomy. Landa (1971) makes a distinction between algorithmic, semi-algorithmic, semi-heuristic, and heuristic prescriptions. Kuljutkin (1970) has elucidated the distinction between algorithmic and heuristic problem solving methods by stating that in heuristic problem solving situations, in contrast with algorithmic ones, the crucial relations are not known; they have to be discovered to find the solution. In the algorithmic situation, the problem solver scans, in a systematic way, a small repertoire of possible relations from which he chooses the crucial one; here there is no discovery of relations, but a check on the presence of known relations.

The distinction between algorithmic and heuristic learning of problem solving is somewhat related -- but not synonymous -- to the distinction between rule learning and discovery learning.

The critical remarks that Wittrock (1966) made while talking about research in the area of discovery learning are relevant here, too. According to his critical remarks, one has in this type of research to take care of: (a) exact operational definition of the treatments, (b) the replicability of the treatments, (c) well-definedness of the criteria, (d) the possibility that each pupil can work according to his own rate and follow hiw own way through the problems, (e) random assignment of pupils to the different treatments, (f) adequate statistical analysis of the results, and (g) premature extrapolation of results.

Some of these points regard the internal, some the external validity of this kind of experiment. Cronbach (1966) adds to this list: (h) the desirability of taking personality factors into account in looking at the

differential effects of the treatments.

We want to add three points to this list: (i) The differential effects of various problem solving methods have to be investigated in relation to the complexity of the class of problems trained; (j) There have to be several criteria, that is, not only tests containing the trained problem types, but also tests containing transfer problem types; and (k) There have to be short and long-term effect criteria.

Research issues

The above mentioned viewpoints are realized in our research project as follows. The differential effects of training in algorithmic versus heuristic problem solving methods are investigated within two domains of thinking, deductive and inductive reasoning. Within these domains the following topics are chosen respectively: (a) judging the logical validity of syllogisms, and (b) extrapolation of number series. Within each topic two levels of complexity are distinguished in such a way that the more complex category contains subtypes that are a superset of the subtypes of the less complex category.

Each of these two categories is taught to different groups of pupils in an algorithmic or a heuristic way. In this way a 2 x 2 design is created. One of the important research issues is the question of whether there is an interaction between the algorithmic versus heuristic factor and the complexity of the problem class.

By presenting the problems and feedback by means of computer-assisted instruction, and using a very adaptive teaching logic, each pupil is going through the problem in his own way and according to his own rate. Feedback and hints can be given in a multiconditional way, based on the recording by the computer of the response history of the pupil. As courseware and

software are necessarily preconstructed, the treatments are exactly operationally defined and replicable.

Pupils are assigned to the four different teaching programs by matching them on pre-test scores.

Important criteria are a test existing of problems of the trained type, and transfer tests, whose content is more or less related to the problems for which a solution method was presented. A distinction is made between horizontal, vertical, and non-specific transfer. All tests are taken three times: as pre-, post- en retention tests. The remainder of this paper regards only the number series extrapolation part of the research.

With respect to aptitude treatment interactions, the following potential aptitudes were chosen: IQ, numerical ability, achievement motivation, negative fear of failure, positive fear of failure, field dependency, interference proneness. The two kinds of fear of failure are described in Hermans (1972). Other terms for these concepts are debilitating, and facilitating anxiety. Pupils with a high degree of negative fear of failure are handicapped by their fear in unstructured and/or stressful situations. In these situations they become underachievers. The reverse is true for pupils who score high on positive fear of failure. It was hypothesized that pupils high on negative fear of failure do better with a problem solving method that offers a high degree of prescription of their behavior, i.e. with an algorithmic method in comparison to a heuristic method. This should not be the case, or even the reverse relation could exist for pupils low on negative fear of failure. No directed aptitude treatment interaction effects were predicted for the other aptitudes. With respect to aptitude treatment interaction, these measures were used in an exploratory way. A positive correlation of IQ, numerical ability and achievement motivation with the criterion variables

was predicted. The factor field-dependency was chosen to determine the effect in situations where negative transfer effects were expected, based on fixedness to learned types of operation.

Method

Subjects

Sixty-four fifth and sixth grade elementary school pupils were trained in extrapolating number series; sixteen pupils were in each cell.

Procedure

For brevety , a very short description will ge given. Pupils took all tests three times: pre-, post- and retention tests. The posttests were taken one to three days after the last training session; the retention tests were taken about two months after the posttests. Each pupil took the programs individually during two or three sessions. Learning time within each category was alike for each matched pair of students.

Apparatus: The instructional programs were controlled by a DEC-PDP-8 computer. Problems and feedback were presented and responses given on different types of terminals: random access image projector, scope (CRT) and teletype.

Teaching logic. A thorough description of the teaching logics of the training programs would be lengthy. Suffice it to say that a small number of standard teaching logics were used in such a way that a very responsive adaptive environment existed. The algorithm is built up of identification and transformation subalgorithms. In the algorthmic version, learning to a criterion took place at the different levels of the algorithm (mastery learning). This is described in more detail in de Leeuw (1975a, 1975b).

Instruction problems test. At the end of the last training session a test containing the problems used in instruction was presented. This

test functioned for the algorithmic program pupils as a criterion of mastery of the problem-category. This test is called the Internal Instruction Problems Test. The test containing the problems used in instruction, that was taken some days later is called the External Instruction Problems Test.

Horizontal transfer test. The test contains figure series that can be reduced to number series of the types in which the students were trained.

Vertical transfer tests. These tests contain number series that go a (few) step(s) further than the ones used in training and/or form a combination of the subtypes used in training.

Non-specific transfer tests. These tests contain: (a) problems requiring interpolation of the trained number series; (b) fixedness problems, that is, problems requiring a quite different approach than the learned ones; and (c) subtests and factor score from the Numerical Ability test.

Results

Some of the most interesting results will be reported briefly. Multiple regression analysis was applied as a method of data analysis. This method offers possibilities to combine dichotomous and continuous independent variables (predictors) in one analysis. The mean scores on the Internal Instruction Problems Test (in percentages correct) for the algorithmic and heuristic groups within complexity level 1, (Algorithmic Category 1 and Heuristic Category 1 respectively), are 93.9 and 77.0, $F(1,30)=6.25$, $p = .018$. For complexity level 2, the means of Algorithmic Category 2 and Heuristic Category 2 are 86.1 and 62.2, $F(1,30)=8.83$, $p = .006$. Within both complexity levels the algorithmic group is achieving at a significantly higher and nearly perfect level. Achievement for category 1

(C1) is somewhat higher than for category 2 (C2) but this difference is not significant.

Generally, it can be said that with the Internal Instruction Problems Test as a criterion, the algorithmic teaching program is overall more effective than the heuristic one. The influence of this treatment factor appears to depend upon the aptitudes of numerical ability or negative fear of failure (an anxiety dimension). The ATI between numerical ability and the algorithmic/heuristic treatment is significant for C1 only, $F(2,29)=10.92$, $p = .003$. For C2 the trend is in the same direction but is not significant. The reverse relation holds for the interaction between negative fear of failure and the algorithmic/heuristic treatment: for C2 this is significant, $F(2,29)=4.69$, $p=.039$; for C1 the trend is similar but not significant. These ATI's are depicted in Figure 1 and Figure 2.

Insert Figure 1 and Figure 2 about here

In contrast the differential effects of the algorithmic/heuristic treatments are reversed for the External Instruction Problems Test, taken some days after the last training session. Overall, the heuristic version, now shows a significantly higher result than the algorithmic one, $F(2,61)=7.75$, $p=.007$. This reversed effect is caused by a very sharp drop in the achievement from Internal to External Instruction Problems Test at the algorithmic level (from 90.0 to 52.0). The achievement of the heuristic group stays at about the same level (from 69.6 to 66.5).

The same type of ATI's that was found for the Internal Instruction Problems Test appears for the Vertical Transfer posttest. Negative fear of failure is an important predictor of achievement in the heuristic group.

The relation of this aptitude with achievement in the algorithmic group is not so strong. The ATI is significant for both C1 and C2 and strongest for C2, $F(3,28)=5.21$, $p=.030$ and $F(3,28)=11.55$, $p=.002$, respectively).

For the horizontal transfer measures, neither main effects or interactions were found. For the problem types for which fixedness to the trained approach could have a detrimental effect, neither main effects or interaction effects were present. Field dependency, measured by the Embedded Figures Test (EFT), however, appears to be a predictor of achievement, especially when the problem class is complex. For the post-test of the fixedness-problems the partial correlations are for C1 and C2 respectively .17 and .42 ($p=.372$ and .022, respectively). This relation between field dependency and susceptibility to set is also found for the retention test of the fixedness problems. Partial correlations are .27 and .41 ($p=.152$ and .023, respectively).

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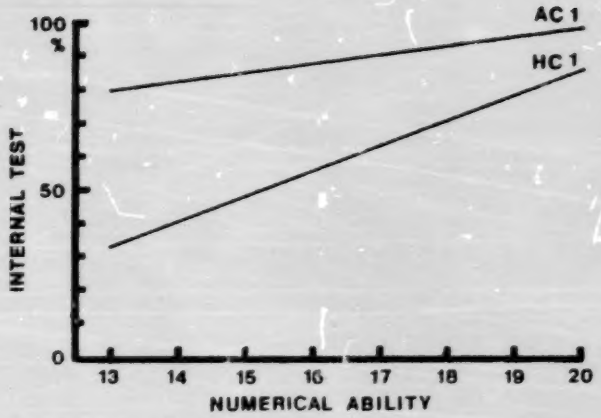
Figure 1. Aptitude treatment interaction between Algorithmic/Heuristic treatments and numerical ability for the Internal Instruction Problems Test.

Figure 2. Aptitude treatment interactions between Algorithmic/Heuristic treatments and anxiety (negative fear of failure) for the Internal Instruction Problems Test.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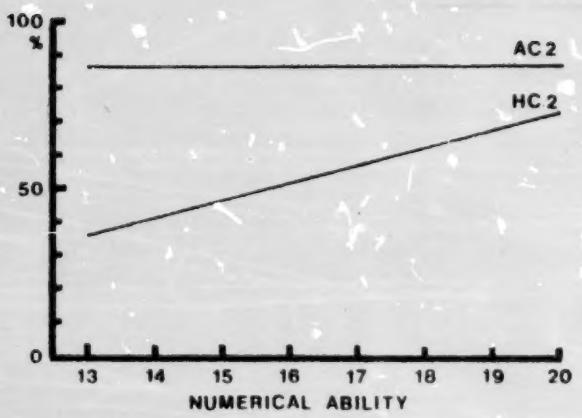
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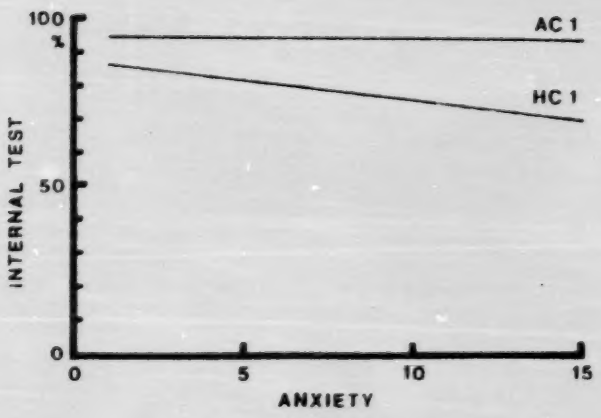
NUMERICAL ABILITY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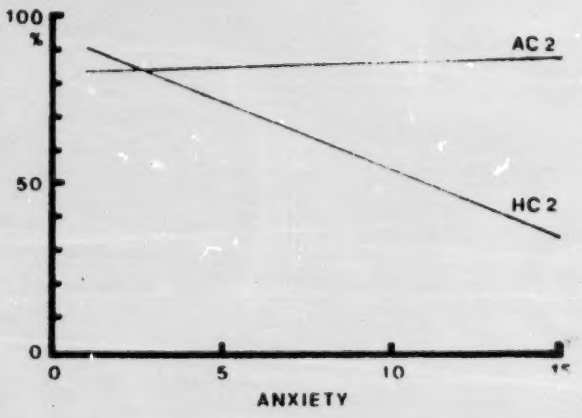
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